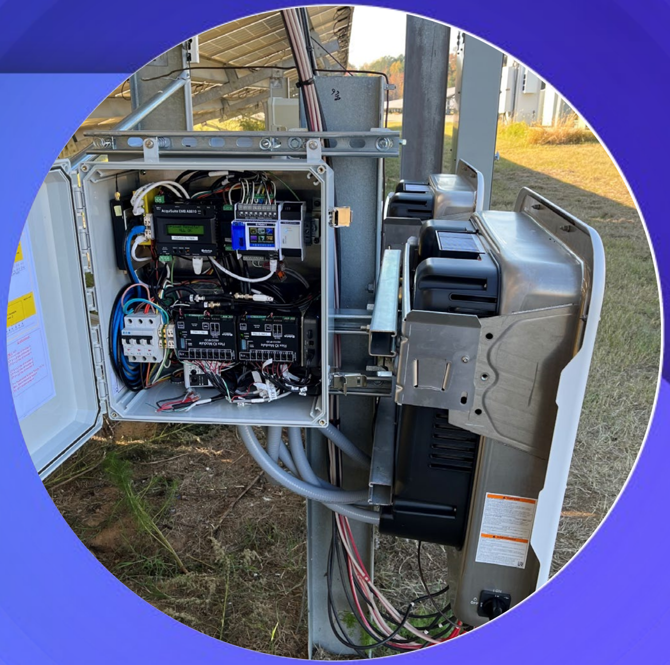
Repowering and Retrofitting of Solar Inverters

A Field Case Study



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November 2024

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Acknowledgments

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Abstract

A handful of large-scale photovoltaic (PV) plants have undergone retrofitting and/or repowering of inverters for a variety of reasons, such as rapid product life-cycle innovations with lack of reverse compatibility, original equipment manufacturers (OEMs) exiting the inverter business, weather damage, more lucrative revenue opportunities driven by high contractual offtake price, and so on. Insights has been collected via expert elicitation and relevant staff involved in these retrofitting/repowering at the case study site. Selecting and installing inverters from a different OEM at the commercially operating PV plant provides a unique opportunity to thoroughly document inverter retrofitting/repowering. The case study describes compatibility of mechanical, electrical, communications, and other important aspects. The goal is to provide a public case study that improves the general knowledge of the solar industry about what is involved in repowering/retrofitting a PV plant and how others can best prepare.

Keywords

Inverter

Repowering

Retrofitting

Solar

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Executive Summary

Deliverable Number: 3002029900
Product Type: Technical Report
Product Title: Product Title: Repowering and Retrofitting of Solar Inverters: A Field Case Study

Primary Audience: Project development, reliability engineering, and operation and maintenance personnel

Secondary Audience: Project financing; insurance; engineering, procurement, and construction; research institutes

KEY RESEARCH QUESTIONS

- What are the critical factors influencing the successful repowering and retrofitting of photovoltaic (PV) inverters?
- How to access the compatibility of mechanical, electrical, communications, and other important aspects while repowering and retrofitting?
- How to retrofit an inverter to improve predictive maintenance practices?
- How to foster general knowledge and understanding of inverter repowering and retrofitting in the PV community?

RESEARCH OVERVIEW

- This study demonstrates the repowering and retrofitting process of a 23-kW OEM1 inverter, replacing it with three distinct inverters—OEM2 (25 kW), OEM3 (25 kW), and OEM4 (36 kW). The necessity for repowering and retrofitting the OEM1 inverter stems from market obsolescence.
- The report describes the incorporation of additional sensors to monitor temperature, electrical signal, and acoustics for improving the predictive maintenance practices while retrofitting the inverters.

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Executive Summary

KEY FINDINGS

- Repowering and retrofitting PV inverters involves unique challenges at each location, necessitating a thorough on-site assessment before the process begins.
- The study emphasizes the importance of selecting reliable equipment during inverter repowering and retrofitting, showcasing the feasibility of three inverters with varying dimensions, costs, electrical designs, and reliability profiles.
- Dimensions and shape of inverters significantly impact rework, compliance with cooling guidelines, and ground-level mounting during retrofitting, particularly considering diverse sizes with similar capacities.
- Optimal performance is achieved by repowering and retrofitting with a high number of maximum power point tracking (MPPT) based on available input strings, and careful consideration of inverter capacity is crucial to prevent overloading or underloading other electrical components, necessitating a comprehensive system analysis.
- Legacy PV plants with limited supervisory control and data acquisition capabilities should undergo assessment and potential upgrades to collect crucial data beyond basic power output, enhancing inverter monitoring and overall plant performance.
- Integration of additional sensors to monitor temperature, electrical signal, and acoustics has proven effective in predicting and preventing component-level failures in inverters, extending their overall service lifetime.

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PROGRAM: Solar Generation, P207

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Introduction: Repowering and Retrofitting

Introduction

Repowering

- Involves upgrades, replacement, or modifications to various components of solar photovoltaic (PV) plants such as PV panels, inverters, and other electrical/mechanical components.
- The main objective of repowering is to improve overall plant capacity, efficiency, and reliability in response to the technological advancements.
- **Example:** Replacing the inverters with other original equipment manufacturers (OEMs) with higher power output capacity or improved efficiency.

Retrofitting

- Refers to the process of adding or modifying specific components of existing PV components to improve targeted component's efficiency or address specific issues.
- The main objective of retrofitting is to improve specific elements of the PV plant to improve overall efficiency and the performance of specific components without comprehensive changes to the PV plant.
- **Example:** Adding sensors to existing inverters to address predictive maintenance and electrical stress of specific components.

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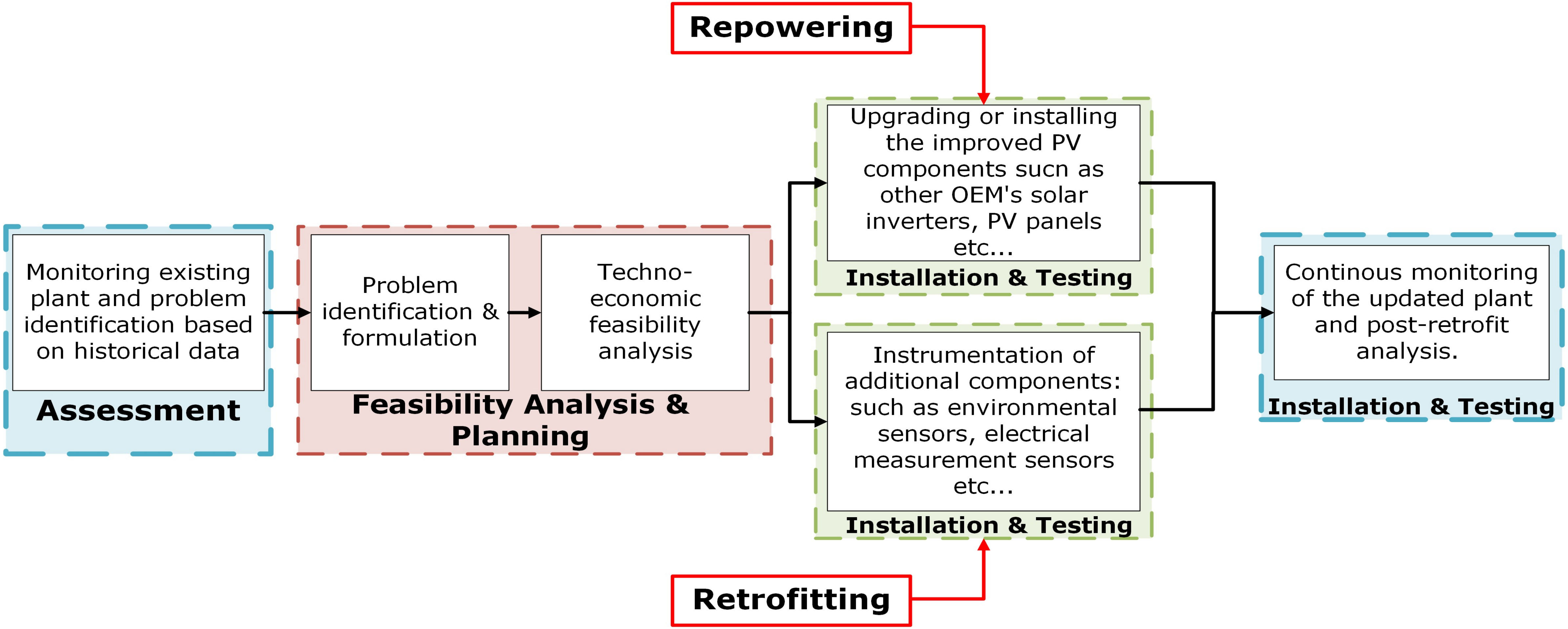
Repowering and Retrofitting



In repowering, new inverters replace existing ones to boost power plant capacity or efficiency; in retrofitting, modifications—including to instrumentation—are made to current or new inverters for specific studies to enhance reliability.

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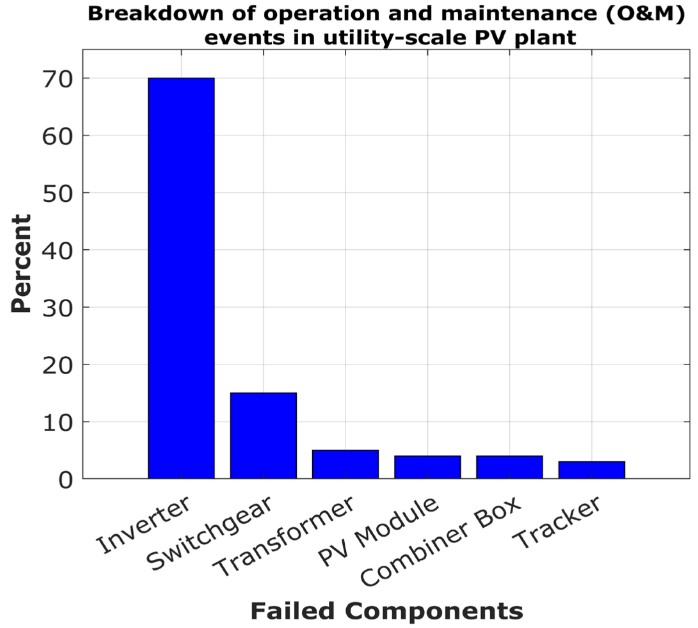
Why Inverter Repowering/Retrofitting?

- <u>Frequent inverter failures</u>
  - Most failed electrical components of PV plant
  - Increased downtime of the PV plant
  - Less revenue
- <u>Repair and maintenance cost</u>
  - Higher repair cost than other components
  - Replacing might be more economical than maintaining
- <u>Limited technical support from OEM</u>
  - Higher lead time for inverter components
  - Less technical support during the inspection, testing, and maintenance (ITM) process
- <u>Technological changes</u>
  - Improved grid standards
  - Rapidly growing solar industry

List of manufacturers having some obsolete * *inverters*

An* ***obsolete inverter* *refers to a model that is no longer in production and is unavailable for purchase in the market. These inverters are typically unsupported by the manufacturer, with no future updates, replacements, or spare parts available, limiting their operational life and making them challenging to maintain or retrofit.*



P. Hacke, et al. Renewable and Sustainable Energy Reviews 2018, 82: 1097-1112 EPRI. TR-102138. Palo Alto, CA: 1993.

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Case Study Site Details

Site Overview: General

- Location overview:
  - Location: North Carolina
  - Year of Construction: 2014
- Electrical overview:
  - Capacity (DC): 29.67MW
  - Power plant rating (AC): 20MW
  - Solar PV modules:
    - ET 300s P672300WB 300W
    - Chint 300s CHSM6612 300W
    - Chint 305s CHSM6612 305W
  - Number of solar PV modules: 98,724
  - Inverters: 23 kW string inverter
  - Numbers of inverters: 866
  - AC protection miniature circuit breaker (MCB): 149 ACP 250A panel board
  - Step-up transformer: three-phase, high-voltage transformer: 13.2 kV rated
  - Number of transformers: 10

Image Courtesy: Google Earth Image of the case study site.

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Site Overview: Existing Inverter Details

- Maximum rated power: 23.2kW
- Operating voltage range: 200V to 960V
- Full-power MPPT voltage range: 600V to 900V
- Number of MPPTs: two (3x strings per MPPT)
- Derating temperature: 45°C
- Communication protocol: RS-485-USS
- DC-to-AC ratio: ~1.4x
- Transformer-less solar inverter

Image Courtesy: OEM1, User Manual

*The OEM has ceased production of the inverter. This model of OEM1 inverter is no longer in production and is unavailable for purchase in the market. Moreover, there is very little technical support available to maintain the inverter with no spare parts available.

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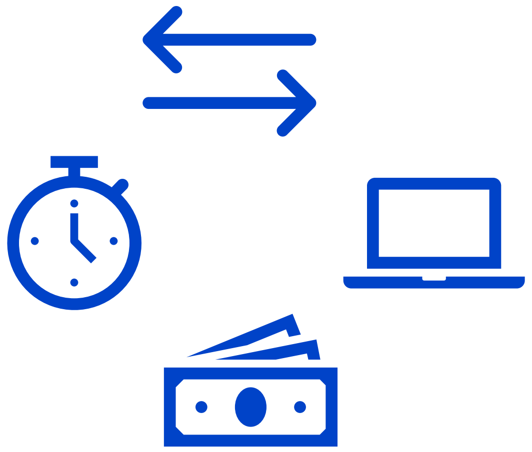
Repowering: Critical Considerations

General Requirements

- Satisfy the electrical system design of existing equipment
- Comply with code
- Minimize the cost of rework
- Minimize system downtime
- Maximize production
- Minimize future operations and maintenance (O&M) costs



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Electrical Design

	Existing Inverter	Potential Inverter Retrofit Options		
	OEM1	**OEM 2**	**OEM 3**	**OEM 4**
DC (Input)				
Maximum DC power	40.6 kW	37.5 kW	37.5 kW	45 kW
Maximum voltage	1,000 Vdc	1,000 Vdc	1,000 Vdc	1,000 Vdc
MPP voltage range	600-900 Vdc	430-800 Vdc	560-850 Vdc	200-1000 Vdc
Number of MPPTs	2 MPPTs (3 strings per MPPT)	3 MPPTs (2 strings per MPPT)	2 MPPTs (3 strings per MPPT)	4 MPPTs (2 strings per MPPT)
AC (Output)				
Power	23 kW	25 kW	25 kW	36 kW
Maximum current	29 A	30 A	30.5 A	43.3 A
Nominal voltage	480 V	480 V	480 V	480 V

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Electrical Design (cont.)

Electrical Design Requirements for Repowering Parameters, Including Inverter Design and Other Considerations	
Diverse AC and DC cable termination configurations	AC/DC terminal boxes significantly affect inverter installation. OEM1 lacks built-in PV connector-type terminals on the DC side, unlike OEM1.
Neutral connection requirements	OEM1 inverter mandates robust AC side neutral and ground connections, while OEM3 and OEM3 offer solutions via physical or firmware updates to bypass the neutral requirement.
Adapt plant design for power fluctuations	Integrating the 36 kW OEM4 inverter into the retrofit requires compliance with electrical plant design, considering its deviation from the initial 23.2 kW OEM1 inverter. Assess the impact on AC components such as wiring, protection relays, and transformers.
Permitting challenge	Retrofitting with OEM2, OEM3, and OEM4 inverters increases the power plant's capacity by 7% to 50%, potentially posing legal compliance challenges.

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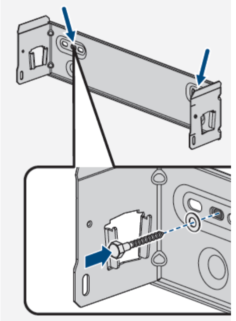
Mechanical Design

<table>
<tr>
<td>Mounting bracket constraint</td>
<td>


The OEM2 mounting bracket necessitates only two supporting blocks, simplifying the installation process compared to the OEM1 setup. This applies to OEM3 and OEM4 as well. The width of the mounting bracket is a critical parameter that must align with the original width to avoid replacement costs and labor hours and adhere to OEM recommendations.
</td>
</tr>
<tr>
<td>Inverter air cooling spacing</td>
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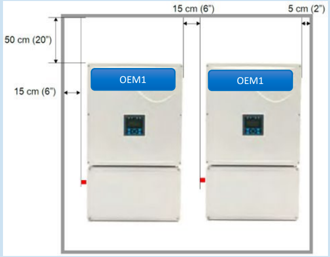

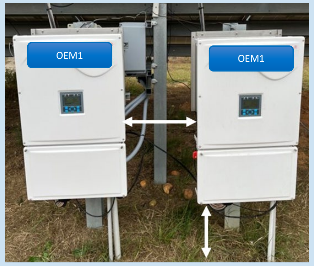

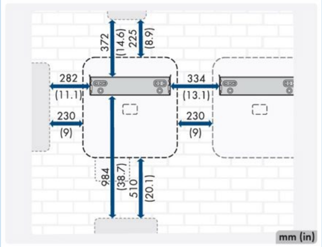

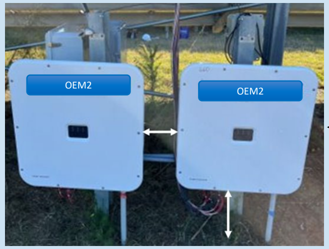

The ground clearance and gap between inverter setups are important for air cooling and other safety parameters. These clearances must be adjusted according to the recommendations in the OEM manual.

Existing inverter spacing configuration V/s repowered inverter spacing configuration (maintained according to OEM recommendation)
</td>
</tr>
<tr>
<td>Leveraging existing wiring infrastructure for placement</td>
<td>To optimize repowering cost, it is recommended to modify existing wiring placement and ground clearance rather than replace the wires with newer components. This procedure should be executed in accordance with the OEM manual guidelines.</td>
</tr>
</table>

Image Courtesy: User Manuals of two different inverters; EPRI©: Site Installation at the Case Study Site

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Other Design Consideration

Various design challenges were observed during the repowering of inverters and based on the observation, the following key considerations during the site installation of inverters are noted

- Make sure cables are protected from vegetation management services
- Minimum ground clearance from most bottom components of the inverter when not over a pad and exposed to vegetation grown below should be 3 ft based on most of the OEM guidelines [1]
- Make sure mounting posts are tall enough to account for various inverter box sizes and variations over the life of the system
- Make sure to follow general safety practices for electrical wiring and mechanical component installation.

[1] Clearance Guidelines for Mounting Three-Phase Inverters - Application Note https://knowledge-center.solaredge.com/sites/kc/files/se-clearance-guidelines-for-multiple-inverter-mounting.pdf

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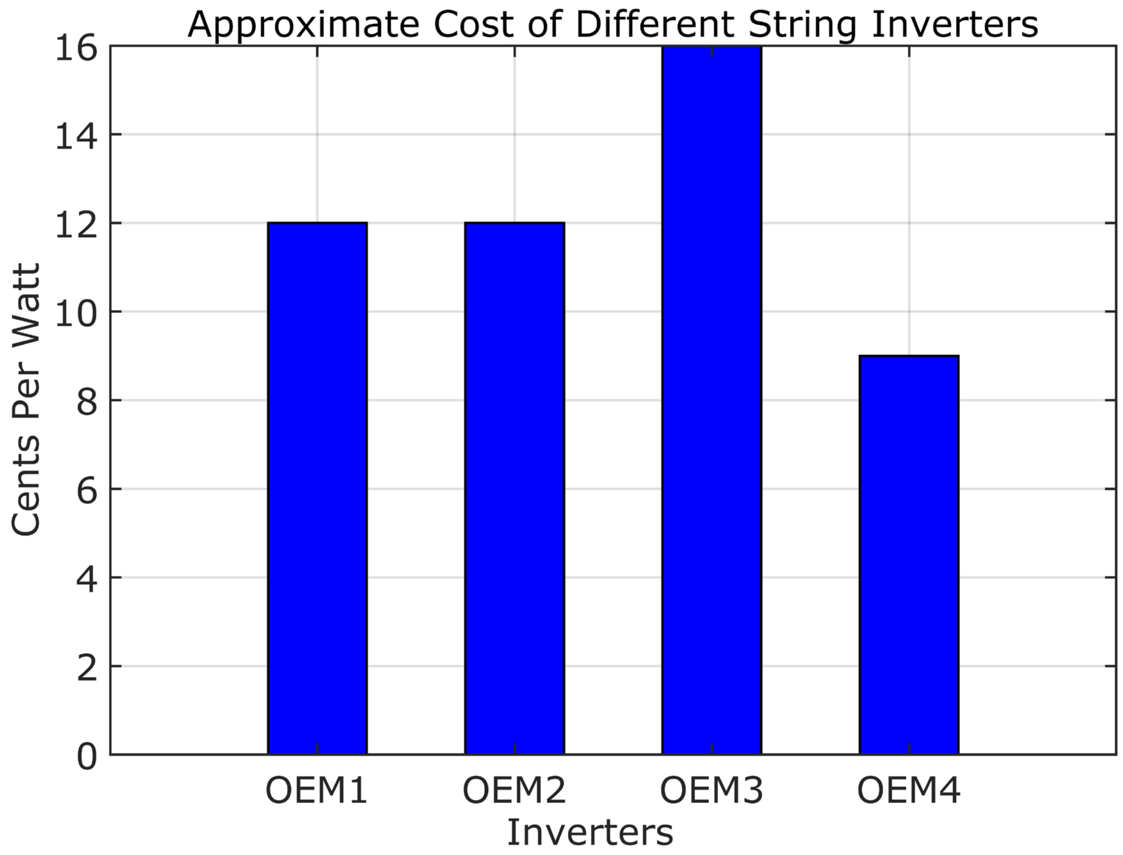
Financial Considerations

- The cost of inverters with comparable capacities exhibits variability.
- The cost analysis of the four inverters in this study reveals a range spanning **9 to 16 cents per watt**. Consequently, the pricier inverter exceeds the cost of the more economical one by **more than 75%.**
- There is no consensus on achieving a reliable inverter through a higher cost, that is, evaluating the trade-off between cost and reliability.
- Nevertheless, there is a prevailing belief among O&M stakeholders that inverters manufactured in the United States and certain European regions exhibit superior reliability. It is noteworthy that inverters originating from the United States and Europe are associated with higher costs compared to inverters manufactured elsewhere.



- If the installation of the new inverters impacts the other system components and requires retrofitting those components at the site, it is essential to conduct a comprehensive financial analysis of the entire system to inform the decision-making process for selecting the appropriate inverter.

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Reliability Considerations

- **Technical support and warranty:**
  - Inverters typically come with a warranty spanning 5 to 8 years, and post-warranty technical support plays a pivotal role in the ITM process. Therefore, a critical reliability consideration lies in assessing the efficiency of technical support provided by the OEM, serving as a key determinant in the selection of an inverter for retrofitting purposes.
- **Market share:**
  - Choosing an inverter based on market share boosts the confidence of the O&M team because it implies choosing a reliable inverter with a strong presence in the market.
- **Derating temperature:**
  - Derating temperature might be a reliability concern while selecting inverter in very cold and hot regions.
- **Inverters features:**
  - Features such as anti-islanding, low voltage ride through, and high voltage ride through make the inverter more reliable as it overcomes the potential faults from grid fluctuations.

U.S. Market Share of String Inverters in 2020

Ranking	Company	Market Share
1	Chint Power Systems	27%
2	Sungrow	17%
3	SolarEdge Technologies	16%
4	SMA	14%
5	Yaskawa-Solectria Solar	8%
6	Fronius	5%
7	Delta Energy Systems	5%
8	Ginlong Solis	3%
9	Fimer	2%
10	Kaco New Energy	2%
	All Others	1%
2020 PV Inverter Shipments (MWdc)		**3,936**

Data Source: Wood Mackenzie: U.S. inverter market share update 2020

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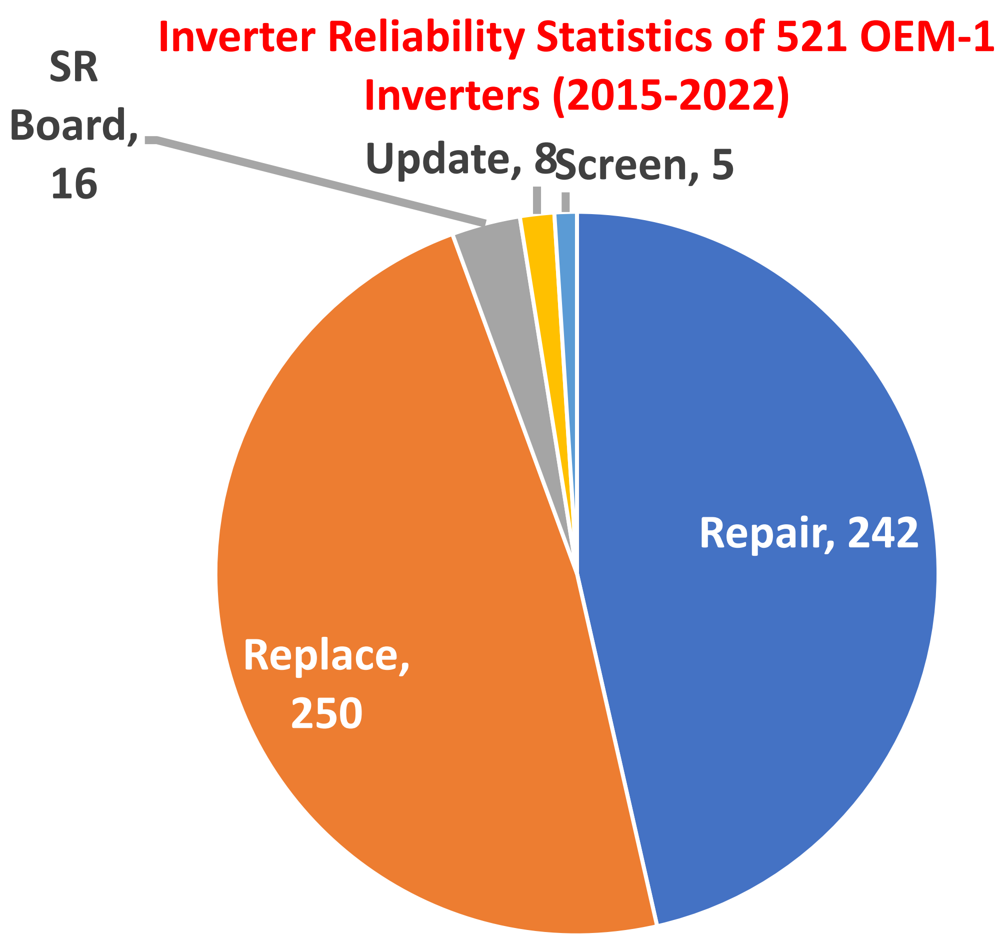
Reliability Considerations (cont.)

- There are currently two common faults that the case study site O&M team is working on.
- First, the signal regulation board experienced catastrophic failure. This board is located inside the upper part of the inverter. The estimated repair time per inverter is 1 hour.
- Second, the inverter requires replacement. This one will take between 2 and 3 hours depending on repair person proficiency.
- There are approximately 50-80 inverter failures every year at the site.
- The mean time to replace the inverter from start to finish—that is, pulling from inventory to installation—is about 2-3 hours for each existing one. This time increases by approximately 1 hour with modifications to different types of inverters.



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Performance Considerations

Power escalation
Retrofitting and electrical design must carefully manage power increments, considering potential impacts on other components. However, such power increases power output and ultimately revenue.

Startup voltage
Startup voltage is crucial in solar PV plant design, managed by series-parallel string combinations. Retrofitting the inverter must avoid excessive increases in startup voltage while decreasing this parameter enhances PV plant performance.

MPPT voltage range and number of MPPTs
MPPT voltage range: This is vital for optimizing power extraction. It should be selected to ensure that the solar PV modules in the existing configuration consistently generate maximum power.
Number of MPPTs: This parameter is integral to electrical design and performance because a higher number of MPPTs results in increased power production. In addition, it contributes to reducing the rating of DC link capacitors and insulated-gate bipolar transistors (IGBTs), enhancing the robustness of the design.

Inverter efficiency
The inverter efficiency is a critical parameter to consider while repowering because this falls under the objective of repowering. However, the claimed V/s actual efficiency is the data that must be sought.

Derating temperature
Derating temperature is an important parameter to look for while finalizing inverter selection. This parameter significantly affects output power in terms of environmental condition, which leads to revenue loss.

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Other Repowering Requirements

Communication system

- Various communication protocols, such as wide area network (WAN), RS-485 (USS protocol, Ethernet Modbus server, remote terminal unit, require specific hardware and firmware to access internal sensor data. This is a critical design consideration for monitoring inverter performance over time.

Troubleshooting inverters

- This relates to inverter commissioning. OEM1 inverters require no extra sources or firmware updates during the initial activation, while newer inverters such as OEM2 and OEM3 may need an app interface and firmware updates. This is vital for efficient inverter retrofitting and minimizing overall power plant downtime.
- Several additional parameters—including noise emission, efficiency, inverter weight, and grid interaction features—must be considered when selecting an inverter for retrofitting purposes.

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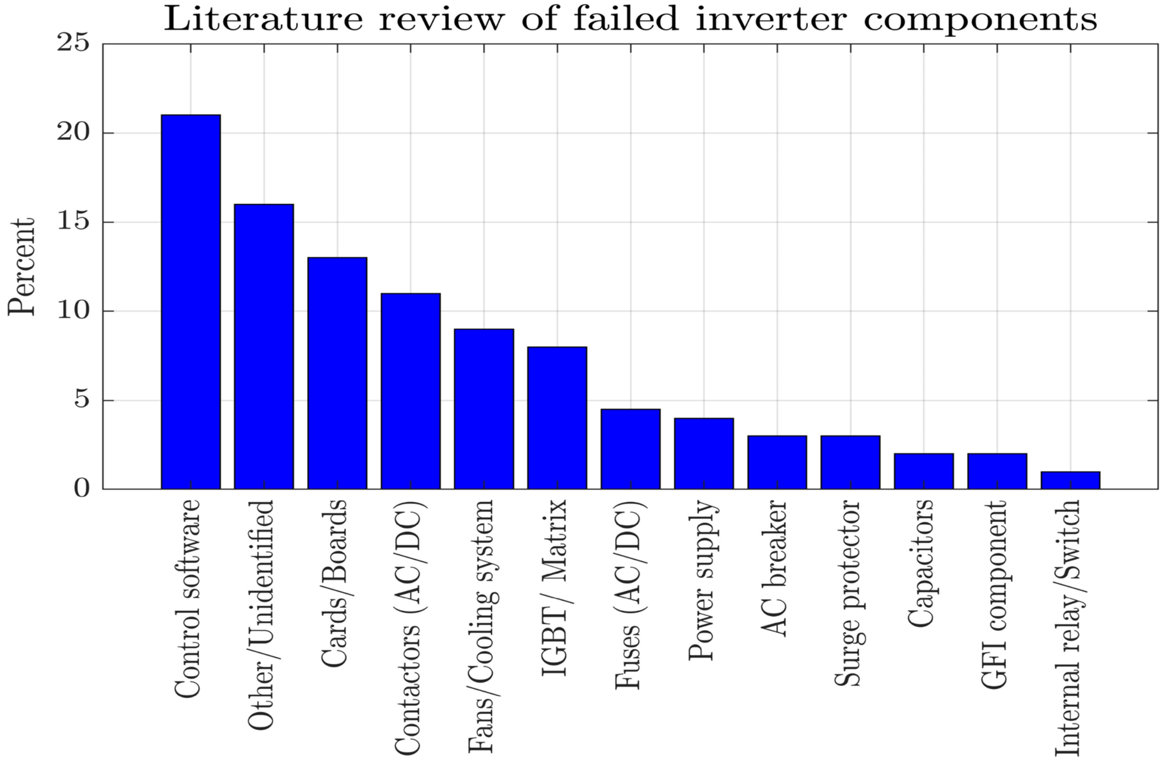
Retrofitting: Critical Considerations

Components That Can be Monitored Based on Literature



Data Source: P. Hacke, et al., Renewable and Sustainable Energy Reviews 2018, 82: 1097-1112

In the study conducted by *P. Hacke et al.,* a comprehensive survey was performed to identify the inverter components that most frequently fail and have the highest impact on O&M (Operation and Maintenance) costs. This allows for prioritizing these components in terms of reliability improvement. The literature survey included data from **approximately 1,500 inverters in 2012**, as well as an older dataset covering the period between 2008 and 2010, which included **around 1,200 inverters from SunEdison**. These inverters were from **16 different vendors**. Along with the SunEdison data, the study also analyzed an **additional 400 field events related to central inverters**, providing a broader understanding of inverter failure patterns and reliability issues.

In this study, we concentrated specifically on components that can be monitored through the retrofitting of sensors. As a result, control software failures, power supply, and other unidentified failure modes were excluded from the analysis. Consequently, the research focuses on the following six components identified for sensor-based retrofitting.

Top 6 Failed Components

1. Cards/boards
2. Contactors (AC/DC)
3. Fans/cooling system
4. IGBT/matrix
5. Fuses
6. Capacitors

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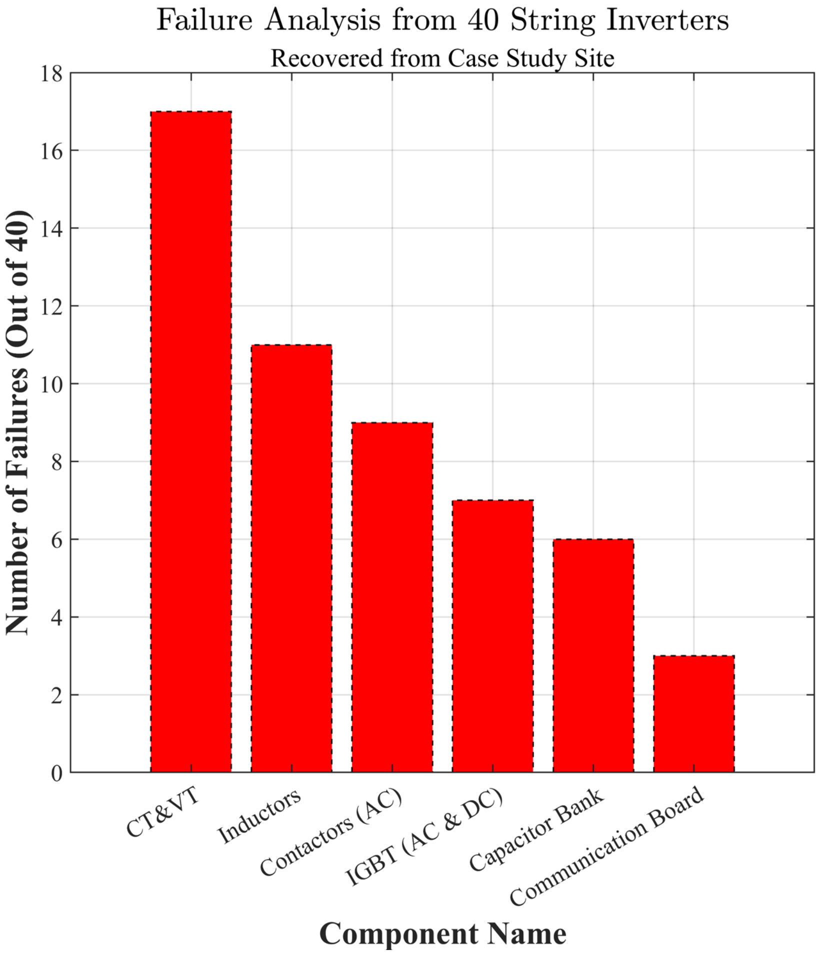
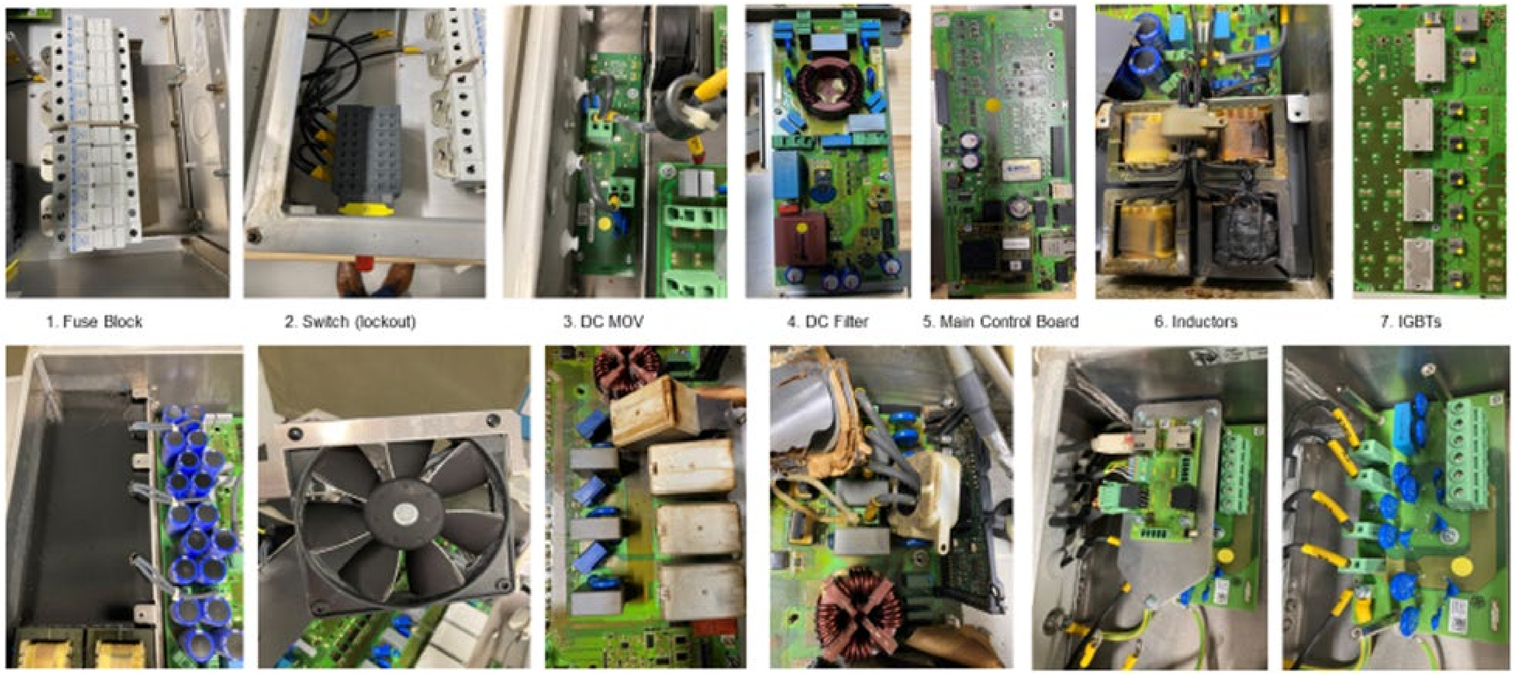
EPRI Research Results: Components That Can be Monitored



The results from the literature review in the earlier slide and the EPRI failure diagnosis on 40-string inverters show partial alignment. However, there are some differences between the two lists, primarily due to the scope of each study. The EPRI study is more narrowly focused, analyzing only 40-string inverters from a single OEM. In contrast, the literature results encompass a broader range of both central and string inverters from 16 different vendors, leading to a more diverse set of findings.



1. Fuse Block 2. Switch (lockout) 3. DC MOV 4. DC Filter 5. Main Control Board 6. Inductors 7. IGBTs

8. Capacitor Bank 9. Fan 10. Contactors (DC) & CT/VT (DC Side) 11. CT/VT (AC Side) 12. Communication Board 13. AC Terminal Board

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Retrofitting Essentials: Key Factors to Consider

1. **Selection of sensors**
   - Sensor selection should satisfy the environmental conditions, type of sensor, power requirements, durability, and reliability of the sensor.

2. **Selection of instrumentation materials**
   - Instrumentation material such as adhering substance, conduits, or other external component should be operational within the environmental conditions and internal temperature conditions.
   - The inverter should be sealed after instrumentation to ensure fair testing and avoid damaging the inverter during instrumentation.

3. **Selection of the data acquisition system (DAQ) components**
   - The DAQ components should be selected to collect all types of sensor data, such as temperature, electrical, acoustics, and humidity.

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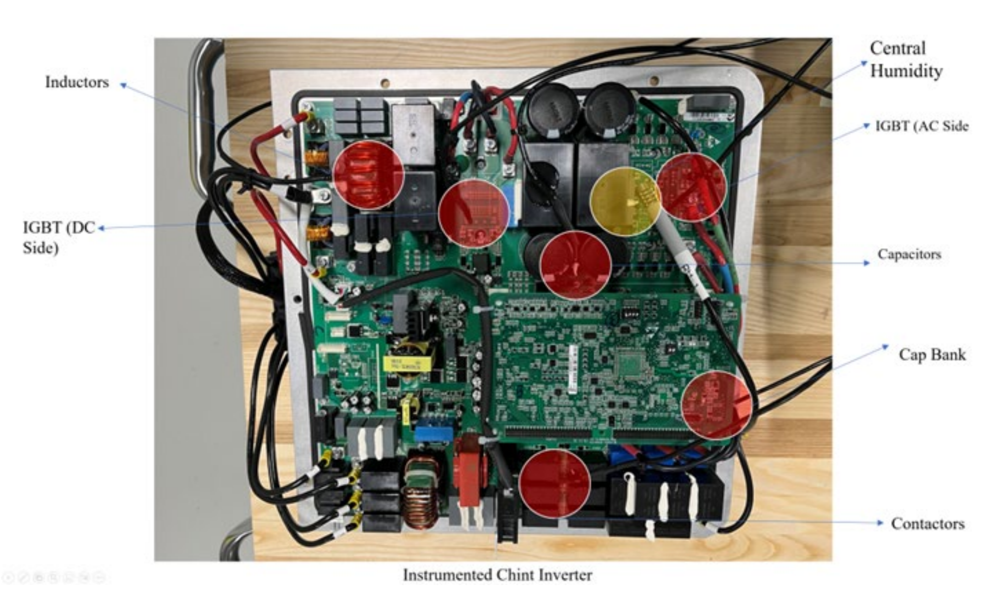
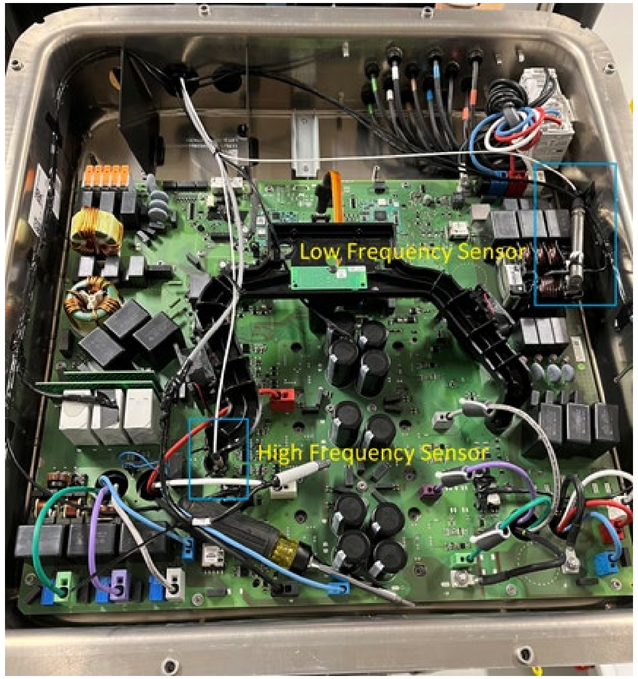
Instrumentation





Instrumented inverters: 1) OEM3, 2) OEM1, and 3) OEM2

→ Number of temperature sensors: **7**

1. Communication board
2. Capacitor bank
3. IGBT-1 (AC side)
4. Contactors
5. Capacitors
6. IGBT-2 (DC side)
7. Inductor

→ Other sensors:

1. Humidity sensor (central)
2. High frequency acoustics sensor
3. Low frequency acoustics sensor
4. Electrical Power Quality Measurement

Image Courtesy: Datasheet of OEM1, OEM2 and OEM3.

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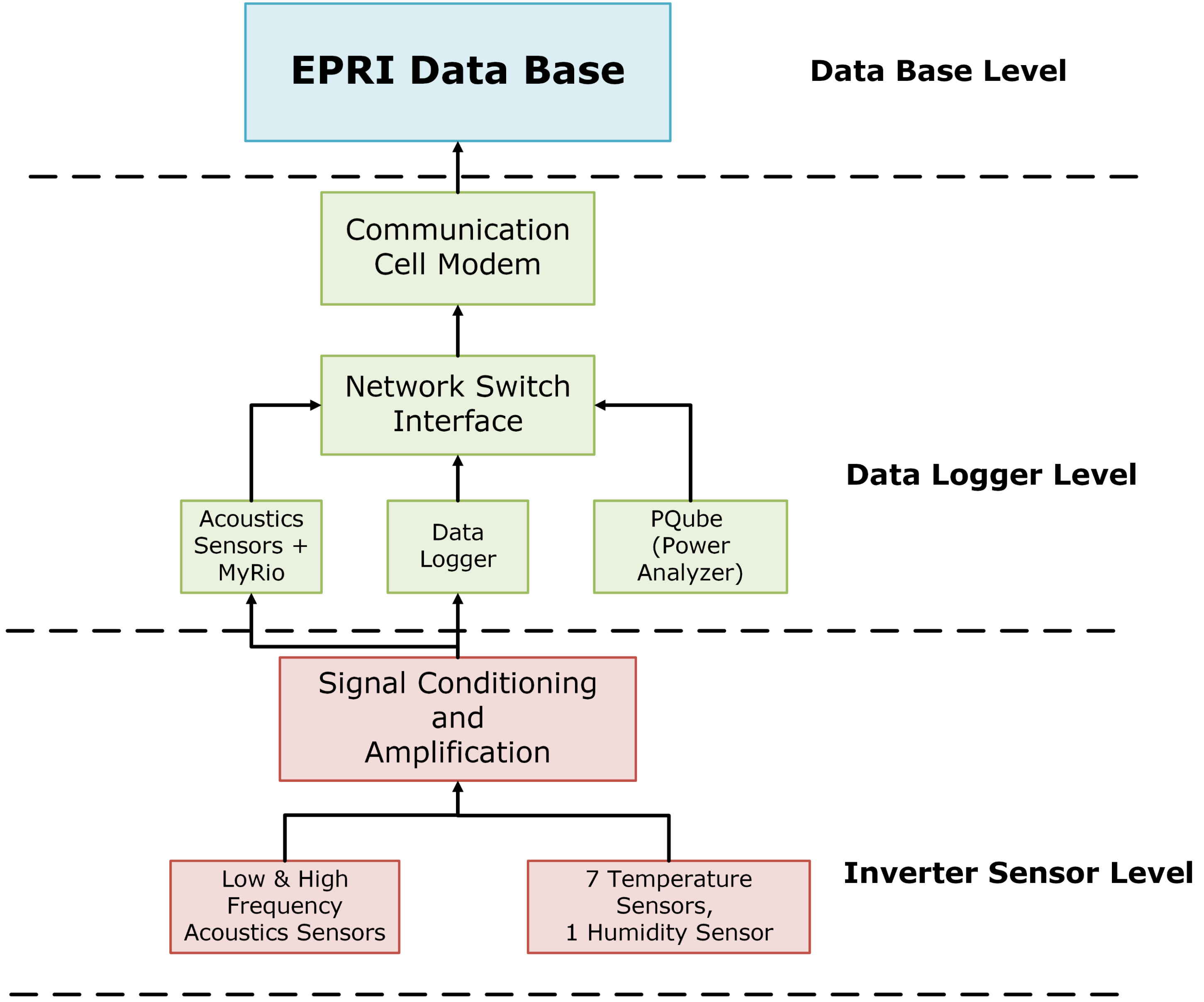
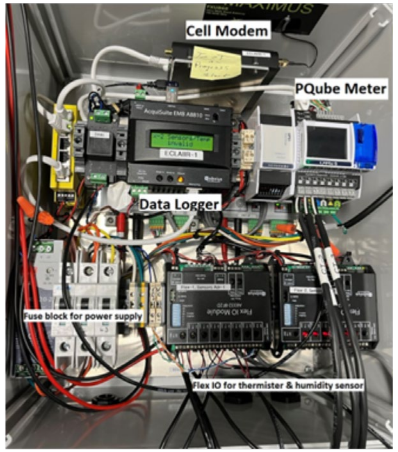
Data Monitoring System

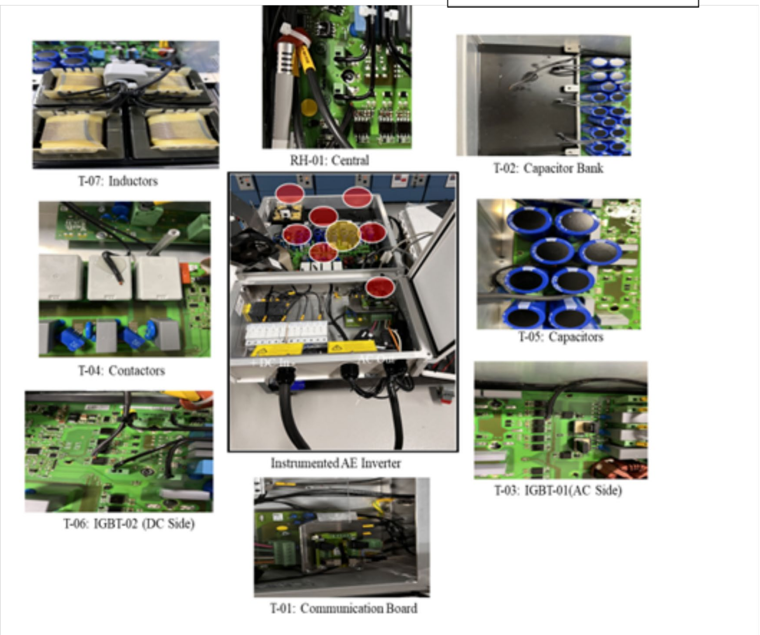




Data Logger Box
Flex I/Os: Collecting the temperature & humidity data
PQube: Collecting the electrical data

High frequency and low frequency acoustics sensors with signal conditioning box

MyRio: Collecting the acoustics data



Sample Instrumented inverter with 7 temperature sensors & 1 humidity sensor

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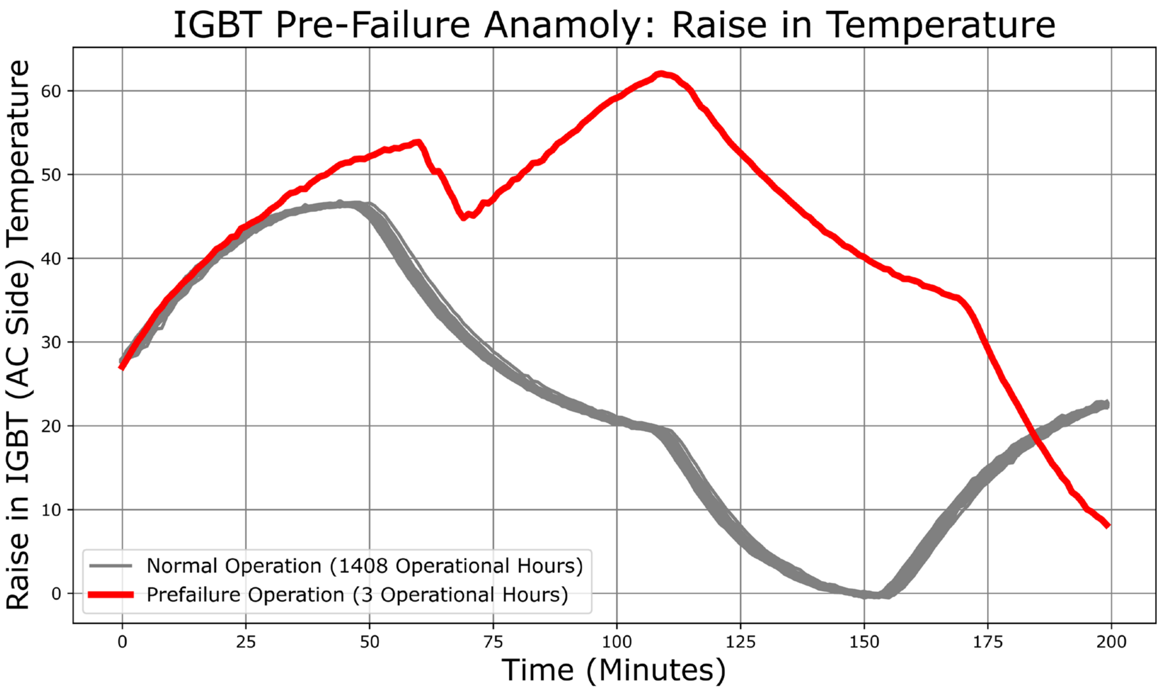
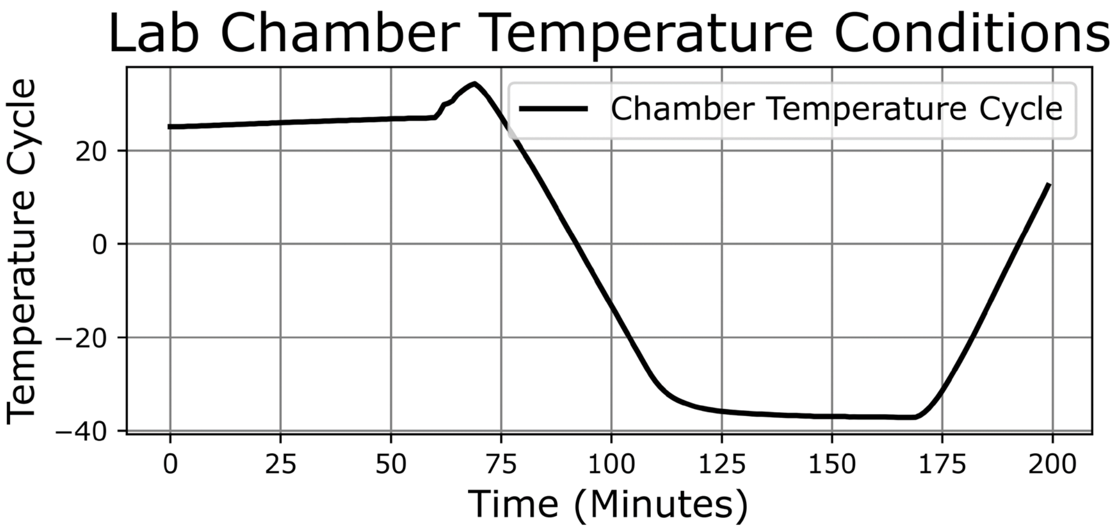
Predictive Analytics Through Retrofitting

Pre-Failure Signature from Temperature Sensor Data





The IGBT (AC Side) is heated about 30^0C - 40^0C more (**Red trend**) than normal operation(**Gray trend**) under the identical temperature cycle.

OEM-3's Pre-Failure Signature: Temperature Signal

Pre-failure signature started to build up a few hours before the failure.

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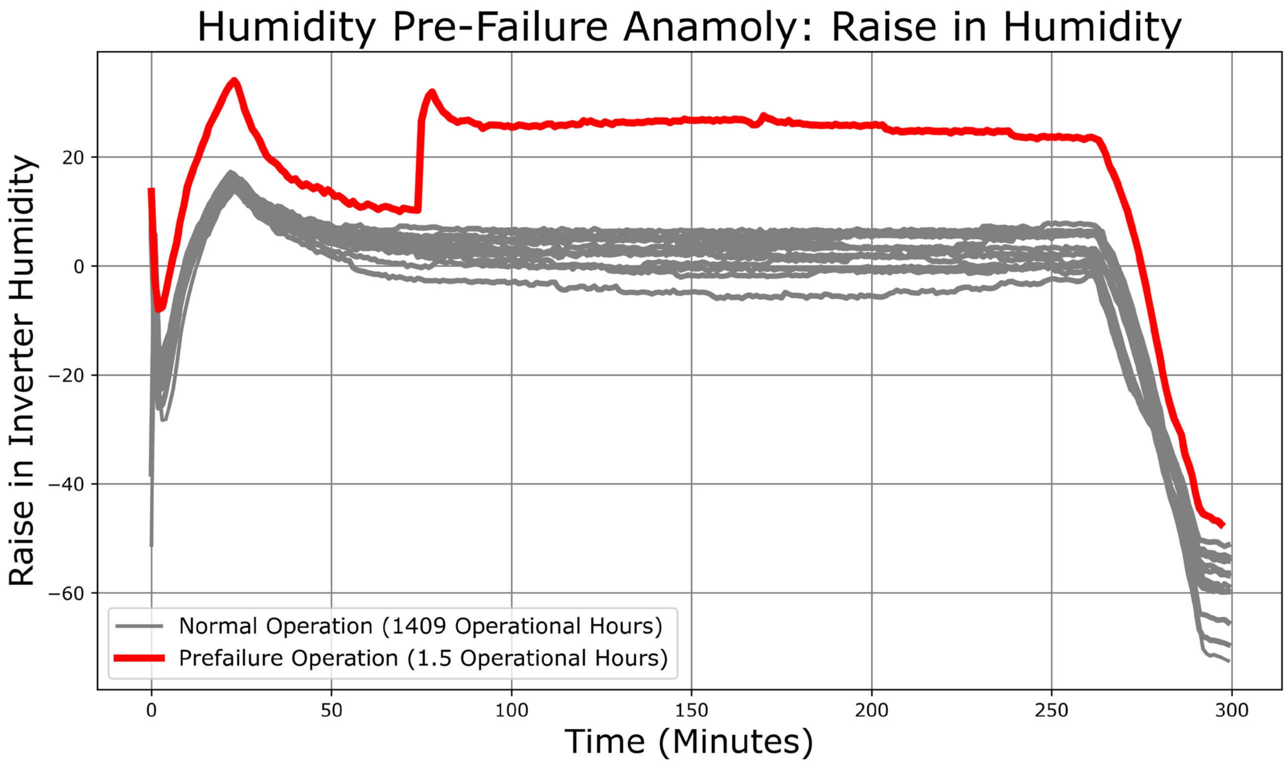
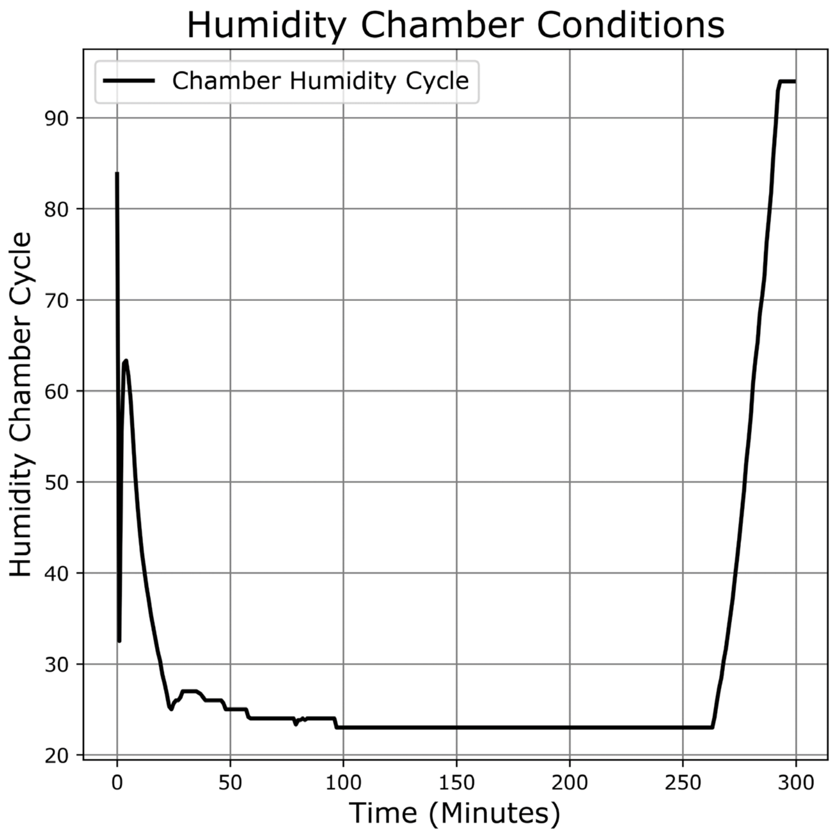
Pre-Failure Signature from Humidity Sensor Data





OEM-3's Pre-Failure Signature: Humidity Signal

The rise in humidity before failure might be because of the production of gases from the electronic components that started to fail from overheating

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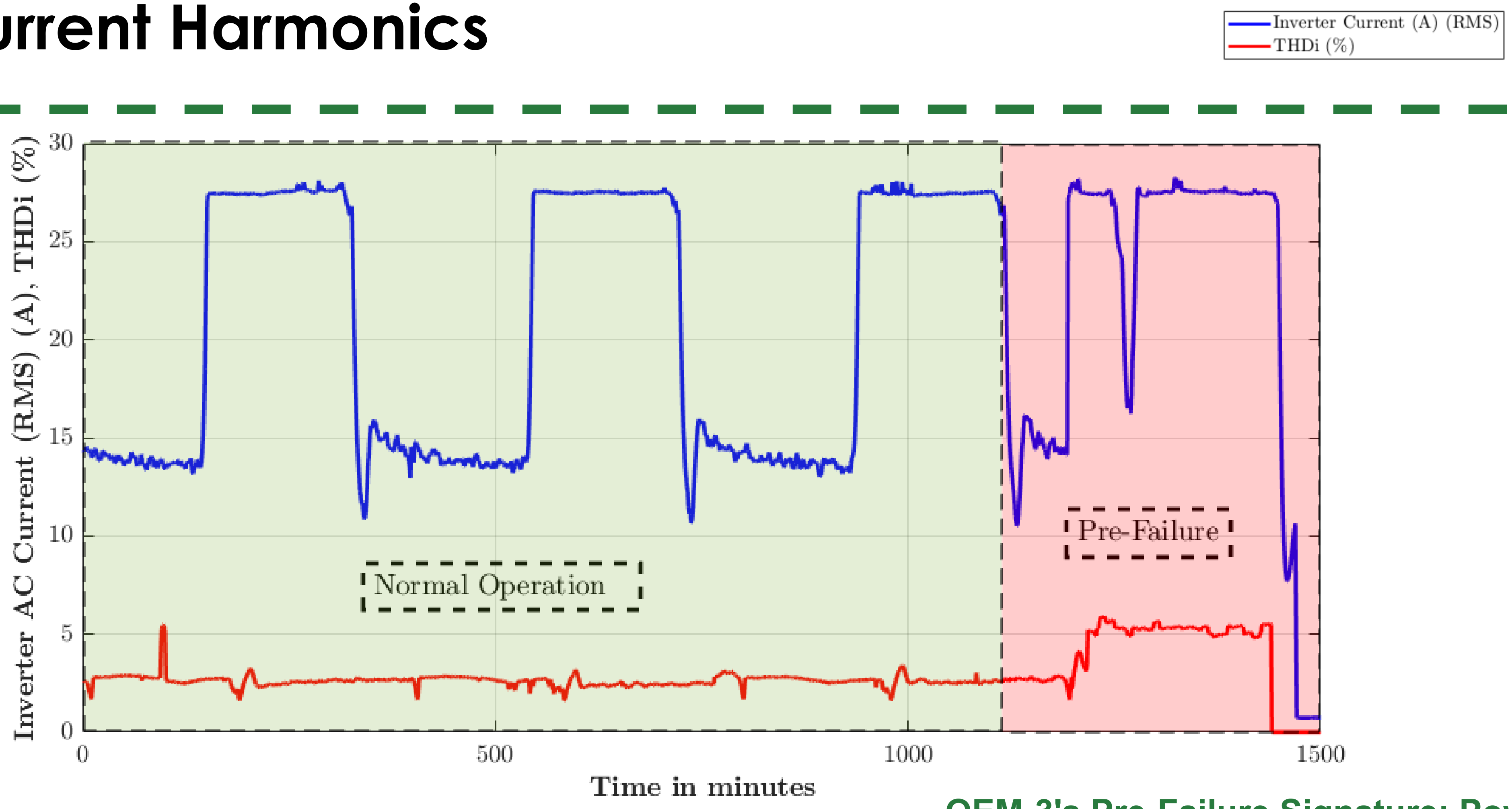
Pre-Failure Signature from Power Quality Meter Data: Current Harmonics



OEM-3's Pre-Failure Signature: Power Quality Signal

The increase in current harmonics might be because of the inefficient operation of capacitors and other components where a pre-failure signature was observed.

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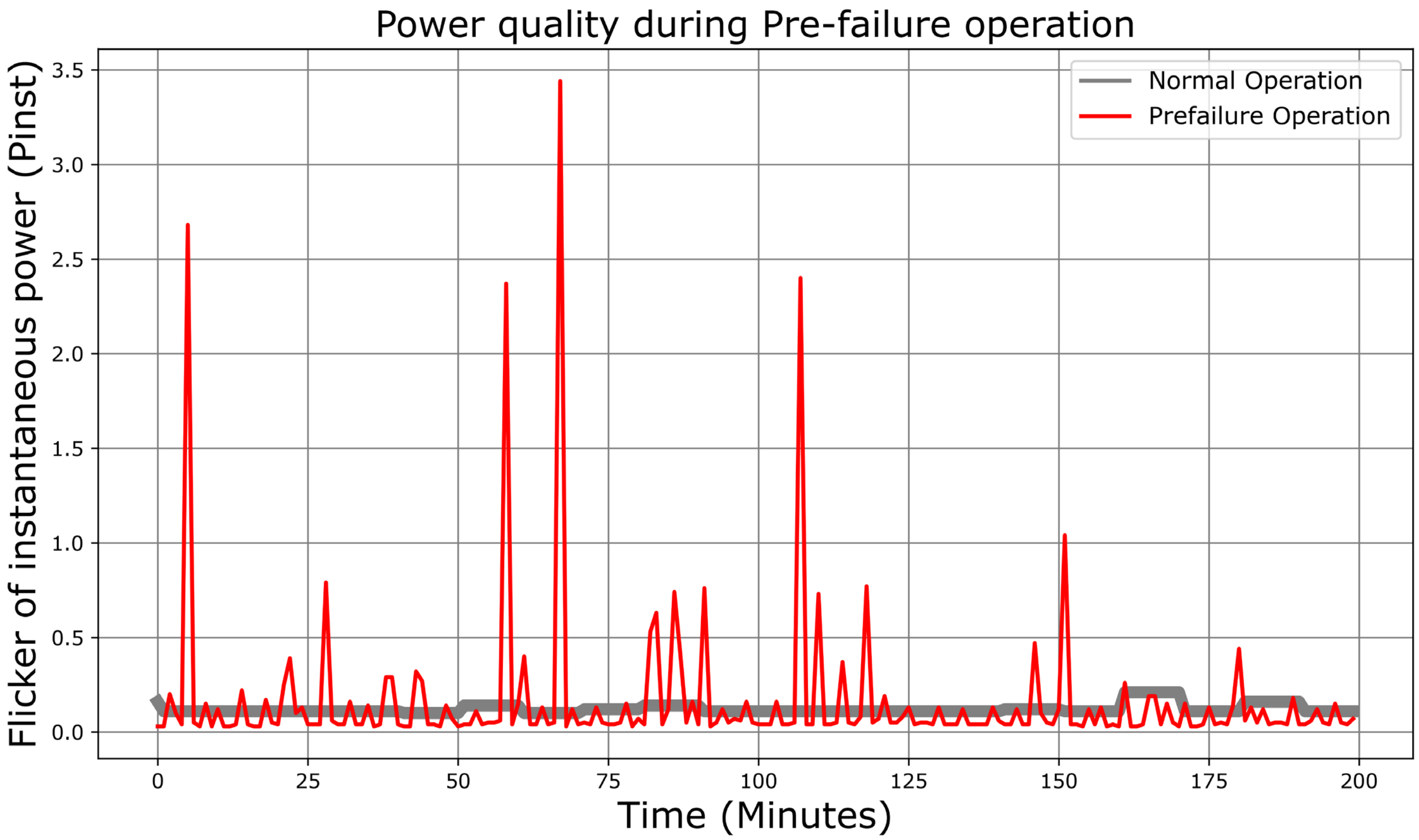
Pre-Failure Signature from Power Quality Meter Data: Power Flicker



Instantaneous power flicker in a solar PV inverter refers to rapid, brief fluctuations in power output, typically caused by voltage changes, inverter malfunctions, or system overloads. These fluctuations can result in noticeable flickering in connected electrical devices.

OEM-3's Pre-Failure Signature: Power Quality Signal- Active Power Flicker

The rise in power flicker could be due to the MOSFET's inefficient switching, along with issues in capacitors and other components that showed signs of impending failure.

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Field Deployment Details

Field Deployment: Overview

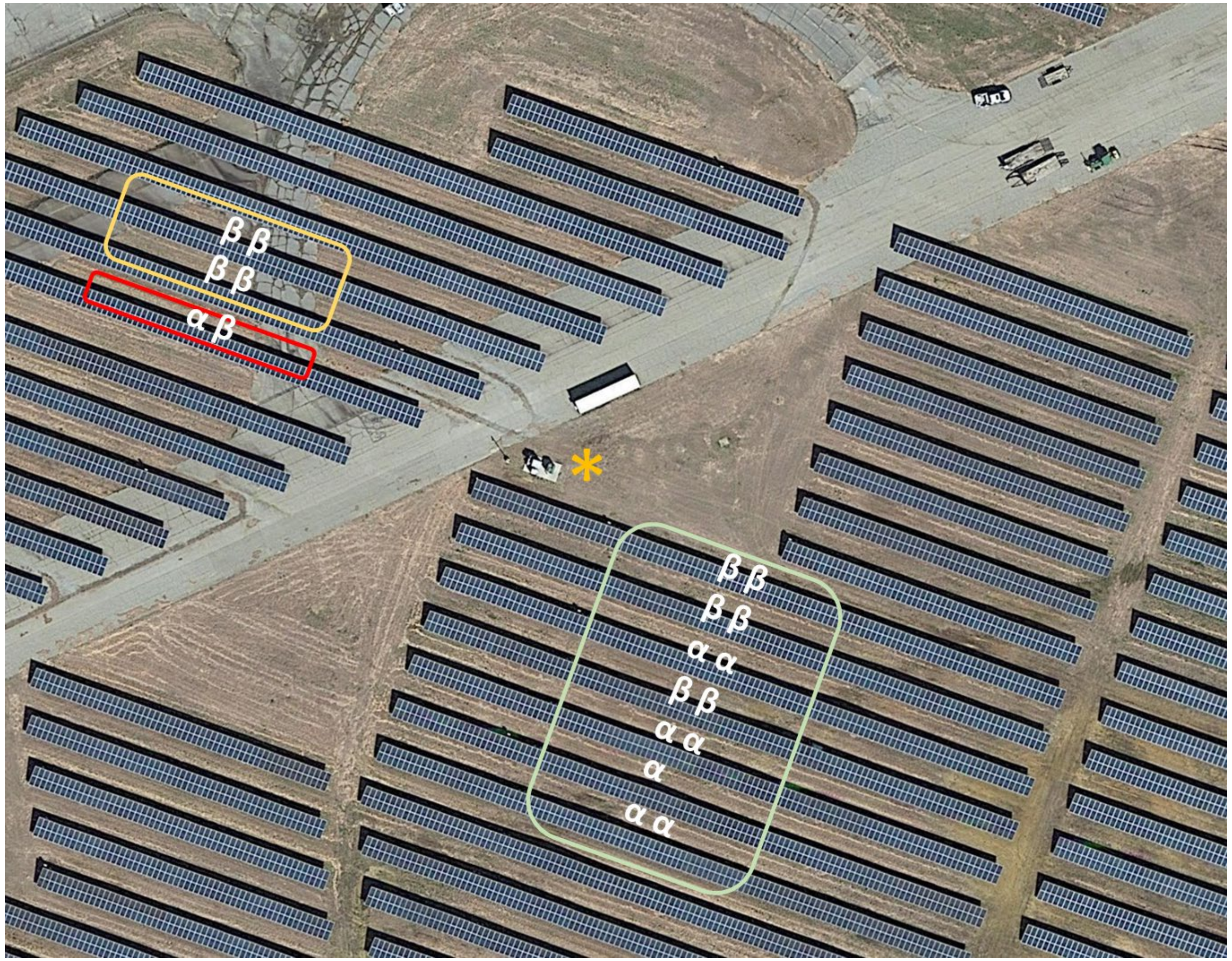

Image Courtesy: Google Earth Image of inverter locations at the case study site.

* = Transformer and switchgear

α = Repowered inverters

β = Retrofitted inverters

----- = OEM1 inverters replaced by new OEM1 baseline inverters and instrumented OEM1 inverters (4x OEM1 inverters; 3x instrumented; 1x un-instrumented)

----- = OEM1 inverters replaced by new OEM1 baseline inverter and instrumented OEM2 inverter (1x OEM1 inverter; 1x OEM2 inverter; 2x instrumented)

----- = OEM1 inverters replaced by new baseline and instrumented OEM2 inverters, new baseline and instrumented OEM3 inverters (5x OEM2 inverters and 6x OEM3 inverters; 3x OEM3 instrumented and 3x OEM3 instrumented; 2x OEM4 36 kw inverters)

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Repowering Example

Repowering with OEM2 inverter

Repowering with OEM3 Inverter

Repowering with OEM4 inverter

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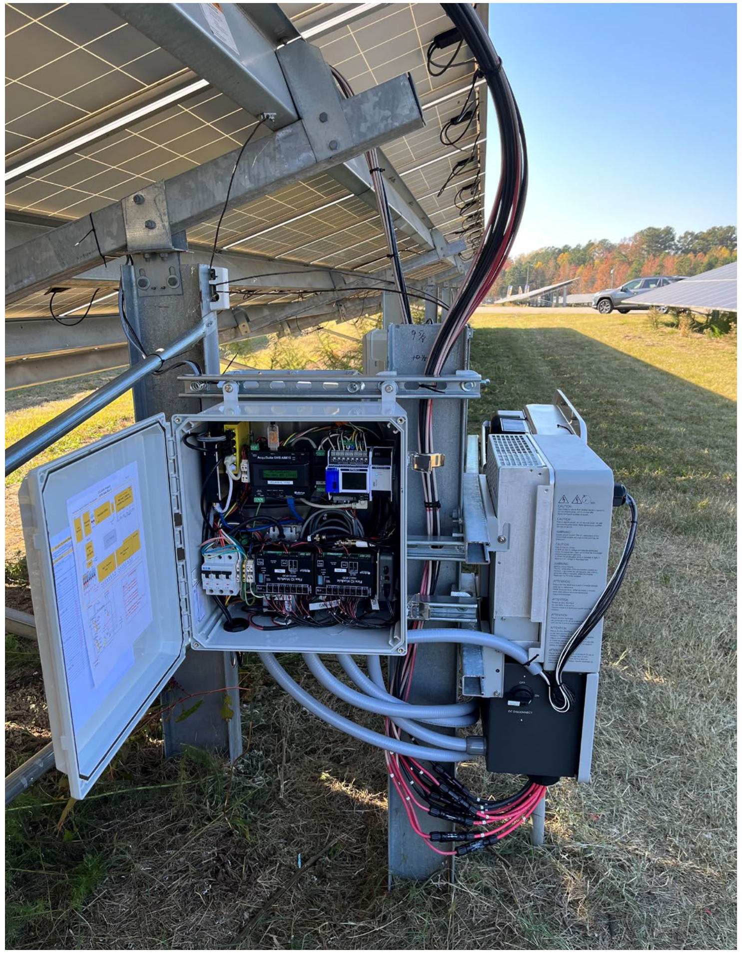
Retrofitting Example

Instrumented inverter (SMA and Solectria) pair retrofitted with data acquisition box



Data acquisition box installation can obtain temperature, humidity, electrical parameters, and acoustics signal

Box with amplifier can amplify the signal from the installed high frequency microphones before sending it to data box

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Takeaways

Key Takeaways

This research serves as an illustration of the repowering/retrofitting procedure for a 23 kW OEM1 inverter, with three inverters: OEM2 (25 kW), OEM3 (25 kW), and OEM4 (36 kW). The repowering/retrofitting of the OEM1 inverter is essential because of its market obsolescence and an annual failure rate ranging from 5% to 10%.

Lessons Learned: Repowering

- Every case study location presents unique challenges during the repowering of PV inverters. Therefore, a comprehensive site assessment through an on-site visit is imperative prior to repowering.
- The primary concern for PV plant owners and operators during inverter repowering is the reliability of the chosen equipment. This investigation highlights the feasibility of repowering with three distinct types of inverters, characterized by varying physical dimensions, cost ranges nearly double those of the most economical inverter, diverse electrical designs, and differing reliability profiles.
- The primary determinants for minimizing rework and complying with guidelines for effective cooling and ground-level mounting position while repowering are the dimensions and shape of the inverters. This aspect is of utmost importance, especially considering the varied dimensions and sizes of inverters with similar capacities.
- Optimal performance is achieved by repowering an inverter with the highest possible number of MPPTs based on the available number of input strings.
- The capacity of the inverter designated for retrofitting should exhibit minimal deviation from the existing one to prevent undue overloading or underloading of other electrical components, including breakers, transformers, and wiring. Consequently, a comprehensive analysis of the new system configuration is essential before finalizing the inverter selection.

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Key Takeaways

Lessons Learned: Retrofitting

- Every case study location presents unique challenges. A comprehensive on-site assessment is crucial for successful retrofitting and installation.
- The retrofit project's success depends on the compatibility of the chosen inverter's dimensions and shape with existing mounting systems and cooling needs, especially considering the varied sizes and shapes of inverters with similar capacities.
- Legacy supervisory control and data acquisition (SCADA) hinders monitoring and performance: Limited data capture (power output only) restricts inverter health insights. Upgrading to capture richer communication data would improve monitoring and boost plant performance.
- Deciding where to attach the sensors can be challenging. For example, OEM1 has 20 capacitors compared to OEM2's 4. Therefore, diagnosing a failed inverter is crucial to determine the appropriate component for sensor attachment.
- Maintaining the original environmental protection of modified inverters is critical. Using IP66 or higher rated waterproof components to seal any wire holes is essential to ensure continued water resistance.
- Capturing high-frequency signals poses challenges because of limitations in bandwidth and storage capacity. We are addressing this by developing pre-processing techniques informed by ongoing research on temperature and acoustic thresholds and relevant frequencies.

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Appendix

Field Deployment (Photographs)

OEM1 inverter pair retrofitted with additional sensors and data monitoring box

Retrofitted data monitoring box and original data monitoring box

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Field Deployment (Photographs)

Retrofitting of OEM2 inverters pair with data acquisition box and amplifier

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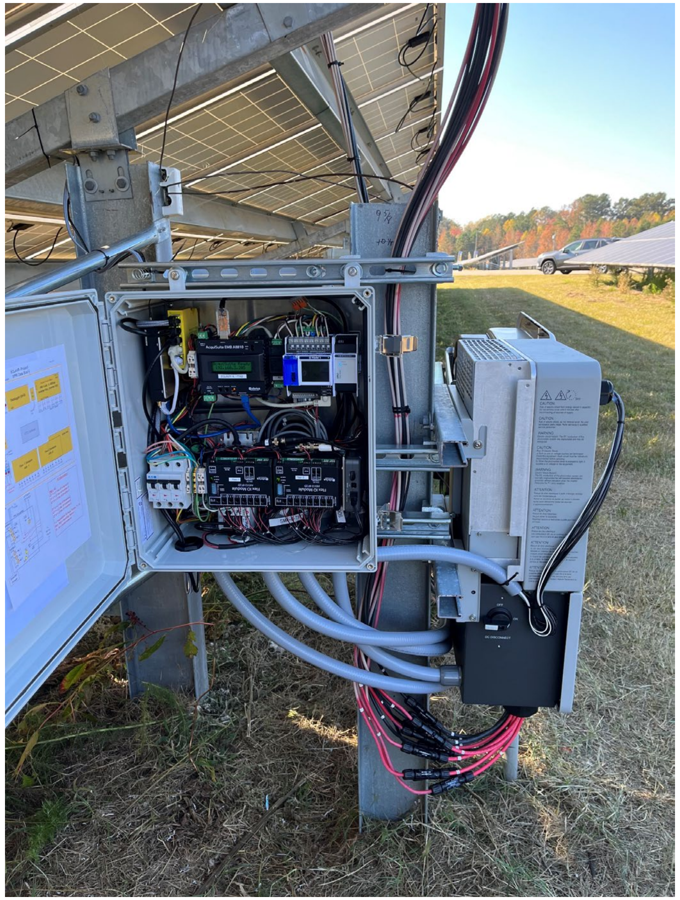
Field Deployment (Photographs)



Retrofitting of OEM2 and OEM3 inverters pair with data acquisition box

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Field Deployment (Photographs)

Repowering of OEM3 and OEM4 inverters pair

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Acronyms

AC	Alternating Current
BESS	Battery Energy Storage System
DAQ	Data Acquisition System
DC	Direct Current
IGBT	Insulated-Gate Bi-polar Transistor
ITM	Inspection, Testing, and Maintenance
MCB	Miniature Circuit Breaker
MPPT	Maximum Power Point Tracking
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
PV	Photo-Voltaic
SCADA	Supervisory Control And Data Acquisition

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References

References

P. Hacke et al., “A status review of photovoltaic power conversion equipment reliability, safety, and quality assurance protocols.” *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 1097–1112, Feb. 2018, doi: 10.1016/J.RSER.2017.07.043.

Inverter Reliability: Status Quo and Best Practices for Predictive Maintenance—A Literature Review. EPRI, Palo Alto, CA: 2022. 3002021731.

W. Li, R. Dhakal, D. Fregosi, C. Fox, and M. Bolen, “Enhancing Inverter Reliability: Current Status and Paths to Predictive Maintenance.” *Conference Record of the IEEE Photovoltaic Specialists Conference*, 2023, doi: 10.1109/PVSC48320.2023.10359723.

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